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A Global Analysis of the Macroeconomic Effects of Climate Change

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We offer global evidence on the macroeconomic effects of climate change for a panel of 22 countries classified by economic groupings. We show that: globally, climate change is inflationary; the negative impacts of climate change on the exchange rate markets is only evident in emerging economies; stock markets could hedge natural climate risks but fail to hedge climate risks due to policy uncertainty.

I. Introduction

The concept of climate change is one of the most debated global issues of the 21st century. Its relevance is not limited to physical consequences, such as extreme fluctuations in precipitation patterns, rising sea levels, hurricanes, wildfires, and heatwaves, but is also concerned with its macroeconomic effects. The macroeconomic effects of climate change can be investigated via the impacts of high temperatures (which are associated with global warming) on economic activity through the effect on labour productivity, efficiency, mortality, and morbidity (Adom & Amoani, 2021). Second, supply chain disruptions caused by damaging climatic events are likely to impact specific prices, particularly food prices. Third, in the face of climate change and climate policy uncertainty, policies may raise carbon price and result in higher production costs, lower profitability, and the value of a company's equity.[1] Few other studies also examine other channels through which climate change could affect the macroeconomic outlook of countries (for instance, productivity/output channel by Acevedo et al. (2020) and price/inflation channel by Faccia et al. (2021), among others).

Given the preceding context, we offer two contributions to the literature. First, unlike the previous studies, we adopt a comparative approach to explore the alternative channels of the macroeconomic effects of climate change globally. We explore the financial channel using stock returns as the proxy for economic activity, the price channel using the consumer price index, and the exchange rate channel to capture the external dimension of the macroeconomic impacts.[2] Second, the few extant studies on the macroeconomic impacts of climate change are largely country-specific.[3] A notable exception is the study of Kahn et al. (2021), which asseses the cross-country long-term macroeconomic effects of climate change; But their study is limited to the output growth channel. Our paper offers a systematic global examination of the macroeconomic impacts of climate change in the context of different economic groupings, across different macroeconomic channels as well as across alternative measures of climate change (temperature anomaly and climate policy uncertainty).

In addition to this introductory section, the paper is organized as follows: Section 2 presents the methodology, Section 3 discusses the findings, and Section 4 concludes the paper.

II. Methodology

We operationalize the analysis of the macroeconomic effects of climate change (and climate risk for robustness) across the globe (for 22 countries[4] that account for more than 80% of the world gross domestic product using a panel data model that accounts for special features of the time series and cross-sectional components of the data. We use the nonstationary heterogeneous dynamic panel data technique put forward by Chudik and Pesaran (2015) and Chudik et al. (2016), and implemented with empirical illustrations by Ditzen (2018). The estimable panel model that accounts for nonstationarity, common correlated effects, and cross-sectional dependence is specified as fol-

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1 See Oloko et al. (2022) for a comprehensive discussion of the equity channel of the macroeconomic impact of climate change.

2 See Faccia et al. (2021) for support on the various macroeconomic channels.

3 The extant studies are predominantly country- or region-specific (Lawrence et al., 2020; Oloko et al., 2022).

4 Austria, Australia, Belgium, Canada, Chile, China, Finland, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, South Africa, Sweden, UK, and US.

lows, for the alternative predictors (i.e. the measures of climate change and climate risk):

$$macro_{i,t} = \alpha_{0,i} + \alpha_{1,i} macro_{i,t-1} + \sum_{j=t}^{t-\rho T} \alpha_{2,i} B_{i,j} + \vartheta_i^{clmc} clmc_{i,t-1} + u_{i,t} \quad (1)$$

$$macro_{i,t} = \alpha_{0,i} + \alpha_{1,i} macro_{i,t-1} + \sum_{j=t}^{t-\rho T} \alpha_{2,i} B_{i,j} + \vartheta_i^{clmr} clmr_{i,t-1} + u_{i,t} \quad (2)$$

$$macro_{i,t} = \alpha_{0,i} + \alpha_{1,i} macro_{i,t-1} + \sum_{j=t}^{t-\rho T} \alpha_{2,i} B_{i,j} + \vartheta_i^{clmc} clmc_{i,t-1} + \delta_i oil_{i,t} + u_{i,t} \quad (3)$$

$$macro_{i,t} = \alpha_{0,i} + \alpha_{1,i} macro_{i,t-1} + \sum_{j=t}^{t-\rho T} \alpha_{2,i} B_{i,j} + \vartheta_i^{clmr} clmr_{i,t-1} + \delta_i oil_{i,t} + u_{i,t} \quad (4)$$

where for $i = 1, 2, \ldots, N$ and $t = 1, 2, \ldots, T$, $macro_{i,t}$ represents either of the three macroeconomic variables (logarithm of consumer prices, logarithm of broad effective exchange rate, and stock returns computed as logarithm differences of the stock price indices) each considered distinctly; $clmc_{i,t}$ and $clmr_{i,t}$ are the measures of climate change and climate risk, respectively; $oil_{i,t}$ is the WTI international crude oil price included as a control variable; the quantity, $\sum_{j=t}^{t-\rho T} \alpha_{2,i} B_{i,j}$, helps to introduce cross-sectional average to the model to correct for the endogeneity bias due to the introduction of the dynamic term (when, $\alpha_{1,i} \neq 0$); $u_{i,t} = e_{i,t} + \gamma_i f_t$ is a two-way error term divided into time-variant (f_t) and cross-sectional-invariant (γ_i) factor loadings and the remainder error ($e_{i,t}$); ϑ_i^{clmc} and ϑ_i^{clmr} are the heterogenous parameters of interest that are obtained through joint significance test (F-test) after including five lags of the regressor series as follows: $\sum_1^5 \vartheta_i^{clmc} = 0$ and $\sum_1^5 \vartheta_i^{clmr} = 0$.

The macroeconomic data for the analysis are obtained from the Federal Reserve Economic Data (https://fred.stlouisfed.org) as follows: consumer prices (Consumer Price Index of All Items, Index 2015=100, Quarterly, Not Seasonally Adjusted), stock prices (Total Share Prices for All Shares, Index 2015=100, Quarterly, Not Seasonally Adjusted), and exchange rates (Broad Effective Exchange Rate, Index 2015=100, Quarterly, Not Seasonally Adjusted) for each of the 22 countries and divided into five sub-panels: full sample, Asia Pacific, Americas, Europe, Advanced economies (G7 countries), and emerging countries (China, India, Indonesia, Mexico, and South Africa) (see Table 1). Climate change is measured with the temperature anomaly data obtained from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS) (see https://data.giss.nasa.gov/gistemp/).The climate risk is measured with the climate policy uncertainty index of Gavriilidis (2021) (see https://www.policyuncertainty.com/climate_uncertainty.html). More importantly, Oloko et al. (2022), Khan et al. (2021), among other notable studies, have also measured climate change using temperature anomalies.

III. Results

We begin the results presentation with the preliminary data analysis of the macroeconomic indicators of interest and the climate change variables. Starting with the descriptive statistics in Table 1, we find little or no difference in the average consumer price indices of the various groups under consideration; and the same holds for the exchange rates. However, while the average stock return is positive for all the groups, the emerging economies appear to have the highest average stock returns; the advanced economies have the lowest average stock returns. Furthermore, Table 2 presents the unit root test results, with the outcomes showing that the dataset is a combination of nonstationary and stationary variables. The outcome justifies our preference for the dynamic nonstationary heterogenous panel estimation technique.

Moving to the focal point of this study, we present the empirical estimates on the macroeconomic effects of climate change in Table 3. The full-sample results reveal the various macroeconomic channels of the global economy as significantly responsive to climate change, both in terms of temperature anomaly and policy uncertainty. However, while the macroeconomic implications appear to be inflationary, irrespective of the measure of climate change considered, the results are mixed when stock returns and exchange rates are considered as measures of the macroeconomic outlook. For example, we obtain evidence of a significant positive impact of climate change on stock returns and report the converse in the robustness analysis. Furthermore, the significance and magnitude of impacts appear to be more pronounced when climate change is measured by temperature anomaly.

To further deepen our understanding of the consequences of climate change on the macroeconomic outlook of the global economy, we further categorised the selected countries of global representative into different groups, namely: Asian Pacific, Americas, Europe, G7 (advanced) countries, and emerging economies. It is interesting that we find the inflationary consequence of climate change significantly evident for all the groups. The consistency of this evidence holds true for both climate change measures (i.e. emperature anomaly and climate policy uncertainty) and when we include the role of control variable. However, the magnitude of the inflationary impact appears to be relatively higher for emerging economies, particularly when climate change is measured by temperature anomaly. More importantly, our finding that stock returns react differently to the alternative measures of climate change (and negatively to climate policy uncertainty) is not surprising as financial markets often react negatively to several policy uncertainty indicators (see Adediran & Akpa, 2022). Finally, we find that the impact of climate change on exchange rate is mainly evident for emerging economies.

IV. Conclusion

This study contributes to the literature by extensively analysing, on a global scale, the effects of climate change from different macroeconomic channels. The study mea-

Table 1. Descriptive and/or Summary statistics

Statistics	Full-sample	Asia	America	Europe	Advanced	Emerging
			Consumer Price			
Mean	4.4856	4.4388	4.4839	4.5310	4.5367	4.3588
Max	4.9278	4.9278	4.8903	4.7712	4.7638	4.9278
Min	3.4787	3.4787	3.9446	4.2877	4.2724	3.4787
Std. Dev.	0.2082	0.2766	0.1895	0.1085	0.1048	0.3426
No. obs.	1,936	616	352	880	616	440
			Stock Returns			
Mean	1.1014	1.4450	1.4677	0.5798	0.4073	2.2114
Max	35.8003	35.8003	17.2438	20.0593	22.4452	35.8003
Min	-60.5522	-45.5832	-37.2435	-60.5522	-37.2435	-45.5832
Std. Dev.	8.4953	9.1586	7.1185	8.6301	7.5754	9.8342
No. obs.	1,914	609	348	870	609	435
			Exchange Rate			
Mean	4.5810	4.5715	4.5774	4.6037	4.5937	4.5436
Max	5.0496	4.9708	5.0496	4.8752	4.8752	5.0496
Min	3.8920	4.2228	4.0874	4.3007	4.2503	3.8920
Std. Dev.	0.1474	0.1626	0.1796	0.0710	0.1212	0.2352
No. obs.	1,936	616	352	880	616	440
			Climate Change			
Mean	0.7372	0.7372	0.7372	0.7372	0.7372	0.7372
Max	1.3609	1.3609	1.3609	1.3609	1.3609	1.3609
Min	-0.1392	-0.1392	-0.1392	-0.1392	-0.1392	-0.1392
Std. Dev.	0.2617	0.2619	0.2620	0.2618	0.2619	0.2620
No. obs.	1,936	616	352	880	616	440
			Climate Risk			
Mean	4.3827	4.3827	4.3827	4.3827	4.3827	4.3827
Max	5.8808	5.8808	5.8808	5.8808	5.8808	5.8808
Min	2.8814	2.8814	2.8814	2.8814	2.8814	2.8814
Std. Dev.	0.7287	0.7291	0.7296	0.7289	0.7291	0.7293
No. obs.	1,936	616	352	880	616	400

sures climate change using the global temperature anomaly data and the climate policy uncertainty index for robustness, and explores three macroeconomic channels: price channel (consumer prices), financial channel (stock market retuns), and exchange rate channel. We employ a dynamic panel data modelling framework that accounts for nonstationarity, heterogeneity effects, and cross-sectional dependence to conduct a systematic global examination of the macroeconomic impacts of climate change across different country groups, such as across continents (Asia Pacific, Europe, and the Americas), and economic structures (advanced (G7) and emerging economies).

On a global note, the results emphasize that the macroeconomic effects of climate change are inflationary. The results reveal that climate change only impacts (negatively) on the exchange rate of emerging economies. Also interestingly, the findings reveal that the stock markets are able to hedge the natural climate risk (temperature anomaly) but not the climate policy uncertainty (which reveals consistent negative impact on the stock returns). The study draws the attention of policy makers globally to the likely inflationary (macroeconomic instability) effect of climate change given the consistent positive response of prices to the two measures of climate change.

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Table 2. Panel unit root test results

Test Method	Full-sample	Asia	America	Europe	Advanced	Emerging
Consumer Price Index						
LLC	-3.9510***a	-5.5618***a	-15.0837***b	-11.1155***b	-14.3268***b	-2.2768**a
IPS	-5.9951***b	-6.1521***b	-5.7489***b	-6.1193***b	-6.0401***b	-5.8068***b
PESCADF	-6.277***b	-3.558***b	-3.869***b	-4.619***b	-2.419***b	-4.776***a
Stock Returns						
LLC	-22.0047***a	-12.3970***a	-10.3188***a	-14.3699***a	-13.1170***a	-10.1938***b
IPS	-5.2960***a	-5.8290***b	-5.4023***a	-5.2005***b	-5.2668***a	-5.3742***a
PESCADF	-6.744***a	-4.933***b	-7.398***b	-5.576***a	-5.121***a	-3.638***a
Exchange Rate						
LLC	-3.7620***a	-13.5771***b	-11.4425***b	-4.4294***a	-2.6769***a	-11.6391***b
IPS	-5.7862***b	-5.3045***a	-5.8596***b	-5.7323***b	-5.6553***b	-5.9498***b
PESCADF	-9.093***b	-4.933***b	-2.926***b	-8.864***b	-1.799***a	-2.981***a
Panel Unit Root Test Results for the Global Variable(s)						
		LLC			IPS	
Climate Change		-10.7224***a			-2.9266***a	
Climate Risk		-5.7815***a			-3.0658***a	

Notes: *a* and *b* denote stationarity at level and at first difference respectively, while ***, **, * indicates statistical significance at 1%, 5% and 10% respectively.

Table 3. Macro-economic effects of climate change

	Full sample		Asia Pacific		Americas		Europe		Advanced (G7)		Emerging economies	
	ϑ	ϑ^*	ϑ	ϑ^*	ϑ	ϑ^*	ϑ	ϑ^*	ϑ	ϑ^*	ϑ	ϑ^*
Main results: Climate change [global temperature anomaly]												
Consumer Prices	0.579*** [48.53]	0.571*** [48.32]	0.742*** [12.43]	0.732*** [12.39]	0.637*** [22.29]	0.629*** [22.10]	0.375*** [209.98]	0.369*** [205.39]	0.335*** [41.11]	0.329*** [41.41]	1.162*** [41.85]	1.148*** [41.79]
Stock returns	3.731*** [17.25]	3.601*** [16.59]	2.802* [3.70]	2.728* [3.57]	0.562 [0.05]	0.497 [0.04]	6.231*** [49.73]	6.038*** [48.28]	5.806*** [94.89]	5.595*** [88.54]	0.277 [0.01]	0.162 [0.00]
Exchange rate	-0.144* [2.95]	-0.145* [3.05]	-0.106 [0.43]	-0.108 [0.45]	-0.261 [0.95]	-0.263 [0.96]	-0.031 [0.39]	-0.033 [0.44]	-0.005 [0.01]	-0.006 [0.01]	-0.623** [5.45]	-0.619** [5.42]
Robustness: Climate risk [climate policy uncertainty]												
Consumer Prices	0.192*** [52.40]	0.184*** [50.39]	0.245*** [13.28]	0.233*** [12.95]	0.213*** [23.66]	0.205*** [21.72]	0.126*** [256.75]	0.119*** [208.45]	0.113*** [38.60]	0.106*** [40.84]	0.379*** [45.71]	0.366*** [45.30]
Stock returns	-1.29*** [35.69]	-1.77*** [73.56]	-1.47*** [31.36]	-1.71*** [23.08]	-1.519** [4.99]	-1.89*** [9.53]	-1.01*** [7.98]	-1.68*** [28.11]	-0.658*** [44.70]	-1.37*** [178.34]	-2.182*** [26.88]	-2.62*** [40.17]
Exchange rate	-0.045* [2.83]	-0.055** [4.11]	-0.039 [0.58]	-0.047 [0.93]	-0.077 [0.86]	-0.089 [1.11]	-0.007 [0.14]	-0.015 [0.62]	0.002 [0.01]	-0.001 [0.00]	-0.195** [5.37]	-0.201** [4.93]

Notes: Panel A is the main result of the macro-economic impacts of climate change measured by global temperature anomaly and the auxiliary result in Panel B is the impact of climate policy uncertainty. ϑ and ϑ^* are the coefficients of the models without and with WTI oil price as a control variable respectively. Values in square brackets are the F-values of the joint significance of the lagged regressor. All the variables are expressed in logs. ***, ** and * signify statistical significance at 1%, 5%, & 10% significance levels respectively.

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